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Risk assessment of PCP lift system using a fishbone diagram and MICMAC method

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Abstract. Hydrocarbons demand by industrialized and developed nations and the oil prices conditions last few years; many companies have turned again to fields that were not previously considered attractive to produce, to identify them as an alternative to meet that demand. This research shows the identification of a condition, which should be taken into account to produce a mature field by progressive cavity pumping (PCP) artificial lift system, an evaluation with the MICMAC method and the identification of the key variables to achieve the development in this practice. The results make possible to identify highest influence elements, which can guide intervention strategies and form the basis to formulate guidelines and policies for the PCP implementation. The results allow us to conclude that pressures and mechanical designs in field wells should be the guidelines for optimum production, the market rate improvement, and the reservoir productive life.

1. Introduction

The oil sector is a strategic asset due to its economic contributions [1]; for Colombia in 2018, this sector contributed 40% total exports [2]. There is a necessity to maintain an optimal and continuous production, to achieve a long productive life of the oil wells.

The main natural resources, which supply the growing energy demand, are oil and natural gas [3, 4]; the prices of these are volatile and they can generate problems the consumer countries economy, to avoid these volatilities the exploitation of these two natural resources is maintained [5]. To optimize extraction processes, improvements have been made in the Artificial lift systems (ALS) [6], but all of them are susceptible to fail.

The systems selection will depend on the conditions present in the reservoir, starting from natural production, then it uses an ALS and ending in secondary and tertiary recovery systems [7, 8]. During operation, the problems may occur in the electrical functioning and mechanical stresses in the production equipment [9], which may generate additional and indirect impacts on other components of the production system [28].

Failure management is effective when it begins prevention and ends with correction [10] these operations may involve high economic costs due to the equipment and maneuvers must be performed; identifying the occurrence frequency of failures allows the design of preventive maintenance plans which will have an impact on improving oil production and reducing incidents and accidents [12].

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This research makes an evaluation of the failures which occur in a progressive cavity artificial lift system (PCP), to identify the key elements which can be used to propose preventive maintenance strategies and improve performance conditions.

2. Methodology

The methodology begins with the oil well production optimization scheme, it identifies failures in a well with PCP they are related through a fishbone diagram, to allow the variables selection which causes the failures. Using the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) method and the identified variables, the key elements for the prevention of system failures are identified. Procedural systematization is organized into three phases:

2.1. Identification phase

A documentary review was carried out in different information sources about the operating conditions of an oil well with a PCP, operation variables were identified and the effects they can generate in the good operation; a fishbone diagram was designed to relate and identify the key variables which can cause failures in the all mechanical system.

2.2. Analytical phase

The MICMAC method was used and the key variables selected to identify the riskiest variables in the production system. The results will be present these variables in the conflict zone, characterized by containing the variables with higher driving power and higher dependence; the identification of these variables will allow the creation of an operation strategic and maintenance plans.

2.3. Propositional phase

Strategies are proposed to manage and control oil wells with PCP, using the identified variables with the MICMAC method; these strategies will allow the design to follow-up plans to increase the reliability of the system and reducing the failure rate in the producing wells.

3. Production optimization in an oil field

Identify the characteristics in the good operation, it allows defining the production plan to optimize its useful life and quantity of oil produced. A production systems description using reservoir energy is presented below.

3.1. Natural flow

The first extraction stage uses the reservoir pressure; this method is known as Natural Flow. The energy of the fluids compressed and stored in the reservoir [13] are sufficient for the fluid to reach to the surface, due to the pressure differential between the reservoir and the surface production facilities; this method generates a reduction in the reservoir (Ps) and well (Pwf) pressure.

These pressure changes generate alterations in the Gas/Oil Ratio (GOR) and an increase in the production of waterreservoir [14]; when the energy of the fluids is not sufficient to produce a differential pressure to raise the fluids, equipment called the artificial lifting system [15], is implemented, which helps to release weight from the hydrostatic column.

3.2. Artificial lift systems

Downhole pumps are installed to suck and transport fluid to the surface, reservoir, rock and fluid conditions will define the best bottom hole assembly (BHA) design. The Gas Lift and Pneumatic Pumping are mechanisms that inject gas or water under pressure in the wells, to deliver energy and move the fluid to the surface, these systems are effective if the fluids do not have a high weight [16, 17]. Other mechanisms use a bottom pump, such as progressive cavity pumps (PCP), electric submersible pumps (ESP) and mechanical pumps (MP), driven by variable speed electric motors; these equipment allow better extraction management due to the ease changing operating speeds. Its greatest problems are in the designs and mechanical efforts generated by the movement [18]; during the operation of the pumping system, problems can arise related to the operation of the electrical equipment, designs of the production string, even in the mechanical efforts generated by the movement [17] this generates failures and operating outputs of the wells, negatively affecting the reliability of the system. this generates failures and operating outputs of the wells, negatively affecting the reliability of the system.

3.3. Progressive cavity pump (PCP)
The document presents a mechanical failure review in PCP systems, below is a diagram of the main components of this pumping system

a **b** **c**

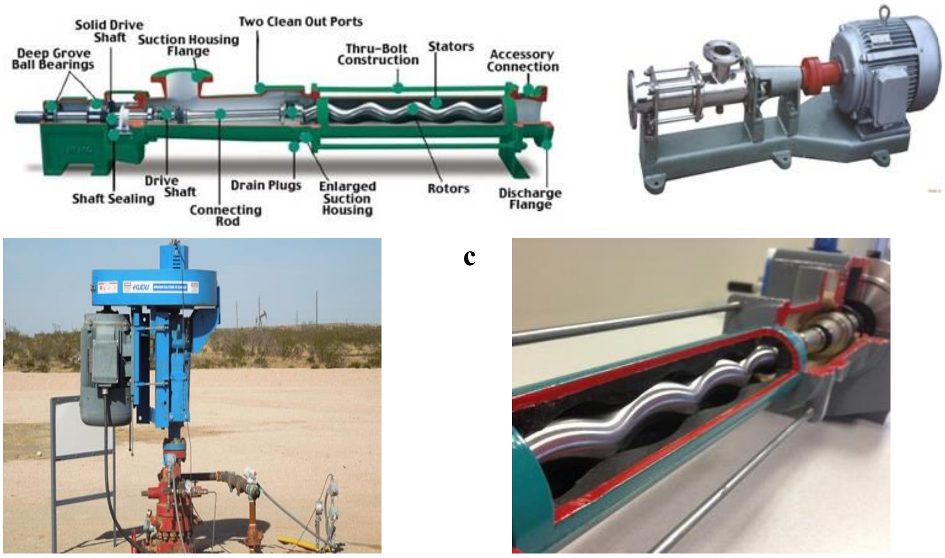

Figure 1.a) PCP system components b) PCP system head c) Progressive cavities internal structure

Figure 1 a, b and c show the design and components of a PCP system, the video in [18] shows the operation of the PCP system. Added to this are the main parts such as the surface equipment in image b and the fundamental bottom equipment in image c, which together constitute the elemental functioning of the progressive cavities

4. Failures in a progressive cavity production system

4.1. Design and Operation Failures
System size and configuration should consider depth, pipe size, fluid volume, and reservoir conditions to define variables such as geometry, stroke length, pump speed, and rod string. Poor design contributes to broke other components, such as tubing cut or rod failures as a result of compressive rod loads [19], presence of corrosive agents in fluids affecting [20] rods resistance producing premature failures [21] When one of the above conditions changes, the design of the artificial lifting system must be re-evaluated [15].

4.2. Fatigue Failure
These failures are of progressive type, identifiable by the fracture profile of multiple parallel marks; they do not present significant plastic deformation and it can start at any point where there is a concentration of stresses [22] The stress on the rod string should be distributed over the length to reduce workloads [23]. The fracture has ductile characteristics and may present edges at 45º [24].

4.3. Flex fatigue failures
Flex fatigue failures cause rods to bend in the failure point. New rods are manufactured with body straightness with no less than 1/16 inch along the overall length of the rod body; a greater degree of

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flexion increases local stress. When the rod is bent and then tensioned straight during loading or axial stress, it will cause the material to break. The pumping cycle increased fluid weight and rod fatigue on the concave side of the flex are the causes of this failure type [23].

4.4. Connection Failures

These failures occur in connection rods with rotary load or also called API rods, due to loss of displacement may occur by improper lubrication, excess or lack of torque, wear by blow of pipes or some combination [23]; cause an adjustment loss and the total uncoupling of the connection [5]

5. Causes and effects related to the failures in a progressive cavity pumping system.

In accordance with the failures described, a fishbone diagram was drawn up relating their failures and their causes [25].

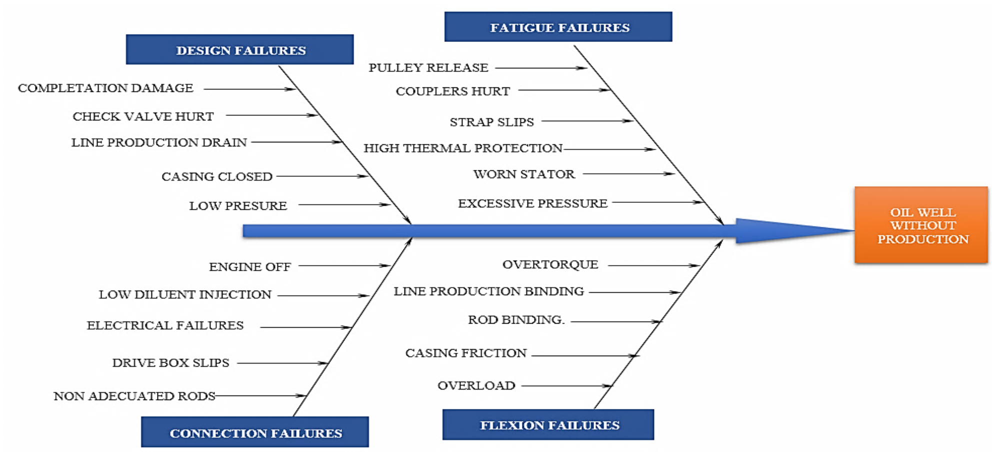

Figura 2.PCP failures in a Fishbone diagram

The figure 2 shows the causes and effects relationship due to failures in the PCP production system, causes allow recognizing the variables which affect the performance and trigger failure. The table selects eleven (11) variables that affect equipment performance.

Table 1. Variables identified from the fishbone diagram.

Code	Variable	Remark
V01	Acid presence	Production of acid compounds, such as H2S, cause changes in the physical properties of good components.
V02	Sand production	Production of reservoir sand, generated by unconsolidated sands or by operational actions; it agglomerate in different parts of the well
V03	Paraffins and asphalt presence	The presence of these compounds can generate scales reservoirs in different parts of the well.
V04	Mechanical design	Lack of consideration of good inclination, fluid petrochemistry, and reservoir petrophysics.
V05	% BSW	A high percentage of water and sediment production.
V06	Active and reactive electrical power	High consumption of electrical energy, generating a deficiency in its production process.
V07	Temperature rise	The temperature increase due to frictional energy losses in the pumping system.
V08	Torque	Increased torque to generate the rotary motion of the PCP system.
V09	Fluid level	Lack of consideration of the static and dynamic well levels.
V10	Gas presence	Increase of the Gas/Oil ratio in the fluid.
V11	PWh	Increased pressure at the wellhead.

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6. Variables Identification by MICMAC

The structural analysis method offers the possibility to describe a system with the help of a matrix linking all its constituent elements [26]. Its objective is to show the main influential and dependent variables and therefore the essential variables to the system evolution.

This method, fundamentally is a tool to structure and organize the ideas, it is composed of three steps, the first is the identification of a variables set which characterize the system; in table 1 the identified variables are observed; in the second step, the matrix of interactions with the identified variables is carried out, a group of participants collaborated to evaluate the influence degree between them, the identified variables were valued from 0 to 5 taking into account the following relationship, (0) null, (1) very low, (2) low, (3) medium, (4) high and (5) very high; the degree of dependence and driving power were calculated. In table 02 and figure 03 you can see the result of the and the dependence vs Driving power diagram. Finally, the identification phase of the key variables, the variables located in the conflict zone are selected due to their high dependence and high driving power; because they have a significant influence on the rest.

Table 2. Cross-impact matrix with the variables in table 1

	V01	**V02**	**V03**	**V04**	**V05**	**V06**	**V07**	**V08**	**V09**	**V10**	**V11**
V01	0	0	5	4	0	0	0	0	3	5	5
V02	2	0	0	5	5	4	0	4	4	0	5
V03	3	4	0	1	0	4	3	4	0	4	4
V04	0	4	0	0	4	5	0	5	5	3	1
V05	0	5	0	4	0	1	4	4	4	0	5
V06	0	4	4	5	0	0	2	4	4	0	0
V07	4	0	5	1	2	4	0	3	2	5	5
V08	0	2	0	4	0	5	0	0	3	3	1
V09	0	3	0	5	5	3	4	0	0	0	5
V10	5	2	5	5	0	3	4	4	3	0	5
V11	5	5	4	5	4	4	1	5	5	5	0

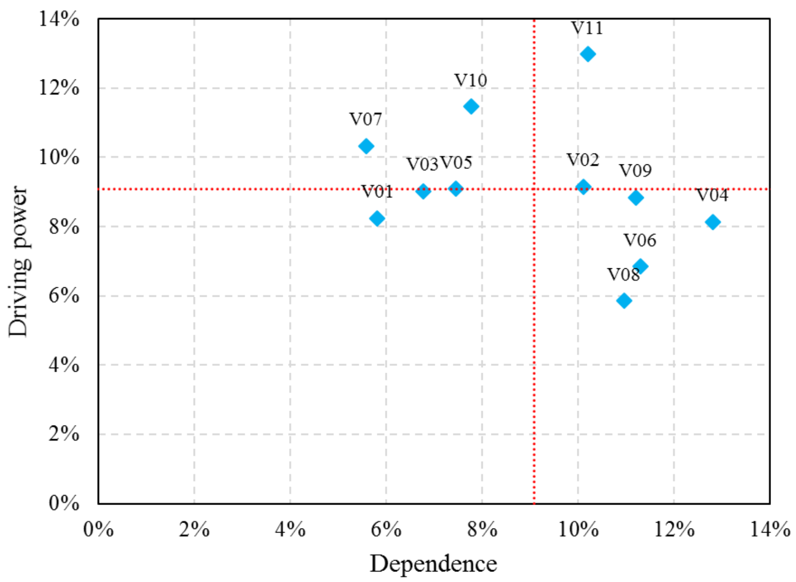

Figure 3. Results obtained from the cross-impact matrix.

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Figure 03 shows the variables V11 (PWh Head pressure), V02 (sand production), located in the upper right zone, they are the key variables or challenge variables of the system, with high driving powers and dependence, which disturb the normal system operation. They are by nature unstable, where V02 is in the conflict zone; and is considered the critical variable to improve the performance and decreasing the occurrence of failures. Located at the top right of the driving power/dependency plane, they have a high level of driving power and dependency, which makes them extraordinary importance variables in the strategic axis. Correct operation requires wellhead pressure control, which is affected by failures caused by high sand production causing a chain of situations that affect the productive life of the well [27].

7. Strategies to prevent failures in progressive cavity systems

The results indicate the necessity to study on variables V02, V09, V11, well conditions, petrophysical variables, and reservoir fluid composition, to identify additional components to the design of the pumping system; a good diagnosis will predict operating conditions to minimize and control well variables, avoiding failures.

- ✓ Equipment implementation is necessary to make the proper system functioning. It can use a grating sand control, gravel pack, grooved Liner.
- ✓ Control the pumping speed, if an adequate speed is maintained, can extend the life of the equipment.
- ✓ Control pumping points when fluid levels are present, it is necessary by placing centering devices to reduce friction and knocking between the rod string and production tubing.
- ✓ Control the excessive presence of released gas.
- ✓ Keep the pump at an adequate level until you have better submergence.
- ✓ Install a gas separator under the pump.
- ✓ Make a correct analysis of fluid properties to optimize equipment subsurface parts selection and materials can prevent future corrosion problems.

8. Conclusions

The research showed the components and failures in the PCP system, one of the most used in shallow wells or those with low productivity. A fishbone diagram was made in which the faiñures causes and effects were identified; allowing the identification and selection of eleven variables which affect this equipment operation. The MICMAC method was used to identify critical variables located in the conflict zone, and the variable V11 (Pwh Head pressure) was the variable with the greatest influence.

The results suggest that analyses should be carried out in the control of production and operation variables which intervene in the monitoring and control process of the well-equipment system, allowing the optimization the production method behavior. Cause of it, the following topics are defined as variables related to the production of the well: production rate of fluids, fluid level, water, and sediments cut (%AyS), viscosity, depth, gas cut. which reflect the conditions that have of operation; with this, it is possible to detect problems in the well opportunely, and it allows to take corrective measures for more efficient operation.

The prevention of anomalies in the PCP system will allow safe and reliable operation, improving oil production and profitability indicators.

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